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Publication date:
2012

Document Version
Publisher's PDF, also known as Version of record

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ABSTRACT

This paper seeks to contribute to the development of Configurational Theory by offering a reinterpretation of the modularity concept from a socio-technical perspective in general and Actor Network Theory (ANT) in particular. By formulating modularity from an ANT perspective covering social, material and process aspects, the modularity of a socio-technical system can be understood as an entanglement of product, process, organizational and institutional modularity dimension. The developed theoretical framework is used for analyzing the modularity of three different production systems the pre-modern, modern and post-modern construction practices.

Keywords:

Configurational theory, Modularization, Actor Network Theory, Construction

INTRODUCTION

In recent years the concept of modularity has been subject to growing attention among academics and practitioners as it is seen as a crucial strategy for handling complexity and risk in post-modern production systems, enabling organizations to produce goods and services meeting individual customers' needs while still leveraging the benefits of similarity and standardization.

In an extensive literature review of modularity in relation to management studies, Campagnolo & Camuffo (2009) identify a complex field of approaches offering different definitions, measures and applications of the modularity concept. Despite the fragmented nature of the field, they identify three units of analysis among modularization scholars – product, process and organizational modularity. Out of the 125 scholars reviewed, only 3 address all three levels. Consequently the relationship between modularity in product, production and organization design not sufficiently studied. They conclude that the development of an all-round framework that encompasses all the three levels is needed (p. 278).

Modularity has been subject to intense research and several scholars have tried to develop a general theory of modularity like Schilling (2000) based on systems theory. However Campagnolo & Camuffo (2009) find that most of the existing works is based on an assumption of technological determinism (p 279). Moreover Fixson (2006) argues that modularity "have been studied mostly in static situations, … however, no system is really static. Products change, processes evolve, organizations adapt, and innovations appear, and all of these changes are accelerating." (p.31)

The outset from system theory, including the technological determinism and stability, makes it hard to explain the dynamic contexts and social entanglements of modularity. Consequently, traditional modularization approaches have some of the same shortcomings as Configurational Theory failing to cope with the social and dynamic characteristics of today's production systems.

AMBITION

The ambition of the paper is to explore the possibilities for understanding modularity from a socio-technical perspective in general and Actor Network Theory in particular. More specifically it is the intention to develop:

an approach for analyzing the modularity of production systems covering both technical and social elements while at the same time incorporate elements of emergence and stability.

Thus the objective is to formulate modularity in a new perspective which might challenge the existing boundaries and open up new avenues of research and practice within Configurational Theory.

METHODOLOGY

The strategy for achieving this is a reinterpretation of the modularity concept from Actor Network Theory. The result is a framework for understanding the modularity of socio-technical production systems. This framework is subsequently used on three cases – pre-modern, modern and post-modern construction practices. The empirical material for the post-modern case stems from an 18 month ethnographic study of a construction project with the aim to develop the school system of a municipality (Thuesen 2006). The material of the pre-modern construction practices stems from an analysis of building works from Copenhagen, Denmark in the period 1850 to 1950 (Engelmark1983). The material for the analysis of the modern construction practices stems from industry reports and analysis of the development of the building industry like (Gottlieb 2010 and Thuesen *et al*. 2011).

THEORY OF MODULARITY

According to Schilling (2000), modularity is a general systems concept, typically defined as a continuum describing the degree to which a system's components may be separated and recombined. Usually it refers to both the tightness of coupling between components, and the degree to which the "rules" of the system architecture enable (or prohibit) the mixing and matching of components (p. 312). Given the open-ended nature of the concept, it is used in a variety of academic and practical fields like biology, nature, ecology, mathematics, cognitive science, industrial design, manufacturing, programming and art and architecture.

Given the broad acceptances of the concept, Campagnolo & Camuffo (2009) argue that every system is modular to some extent. This gives rise to different ways of understanding and describing modularity. According to Fixson (2003), the modularity of a system can be described by either focusing on the elements or relations as illustrated in the following figures.

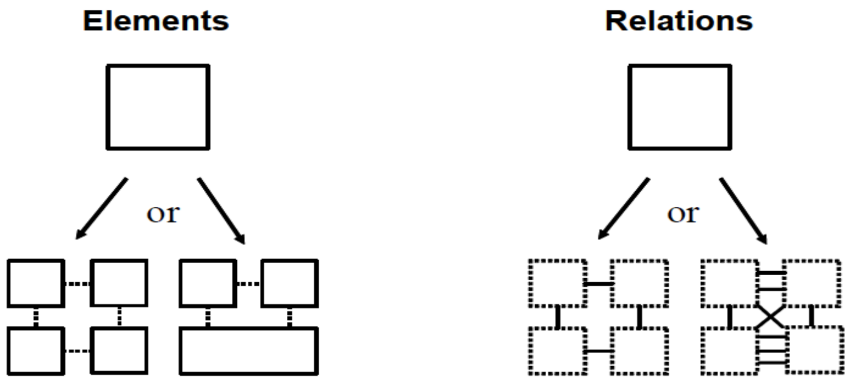

Figure1: Modularity understood as elements or relations (Fixson 2003)

In Campagnolo & Camuffo's (2009) review of the concept of modularity, they indentify three streams of literature clustered around three different units of analysis: (a) product design modularity, (b) production system modularity; and (c) organizational design modularity (p. 260).

Despite the growing interest in the concept of modularity, Campagnolo & Camuffo (2009) find no rigorous studies capable of linking the three perspectives (p. 277). The differences and similarities of existing approaches to modularization set requirements for bridging product, process and organizational modularity. Thus a reinterpretation of the concept of modularity should be able to understand a system with physical and material artifacts, social actors and must be able to handle stability and dynamism… This is basically what Actor Network Theory (ANT) tries to do.

REINTERPRETATION THROUGH ACTOR NETWORK THEORY

How can we describe the modularity of a socio-technical system[1], when it in one moment appears as a closed box, but at other times seems to consist of a jumble of elements and relationships? This is in its simplicity and in all its complexity, what ANT is concerned with.

[1] The concept of socio-technical system is here used as a metaphor for the empirical world covering both human and material elements whereas ANT represents a method for understanding this socio-technical world.

ANT is a theory of technology, science, social actors, society, nature and power, all analyzed with the same conceptual framework (Callon 1986; Law et al 1992; Latour 2005). Although ANT is not one unified theory, there are some key concepts such as network, actors and translations - concepts that spread far beyond the ANT's various research positions.

Actor Network Theory enables us, with the fundamental notions of "actor and network", to understand how important components (actors) of a socio-technical system are tied together (networked) and produces action (translation).

Unlike other theories about modularity, ANT is not a normative theory but an approach for understanding a socio-technical system without subscribing predefined analytical categories such as organizational, product or process modularity any importance. These categories might arise through analysis of the central concepts (actors, networks and translation).

Network

Compared to the common understanding of modularity, ANT operates with a different topology - a network metaphor similar to the relational position that Fixson (2003) identifies. As illustrated in the following figure, ANT is based on a relational understanding of networks consisting of tangible and intangible, human and non-human actors - which are heterogeneous.

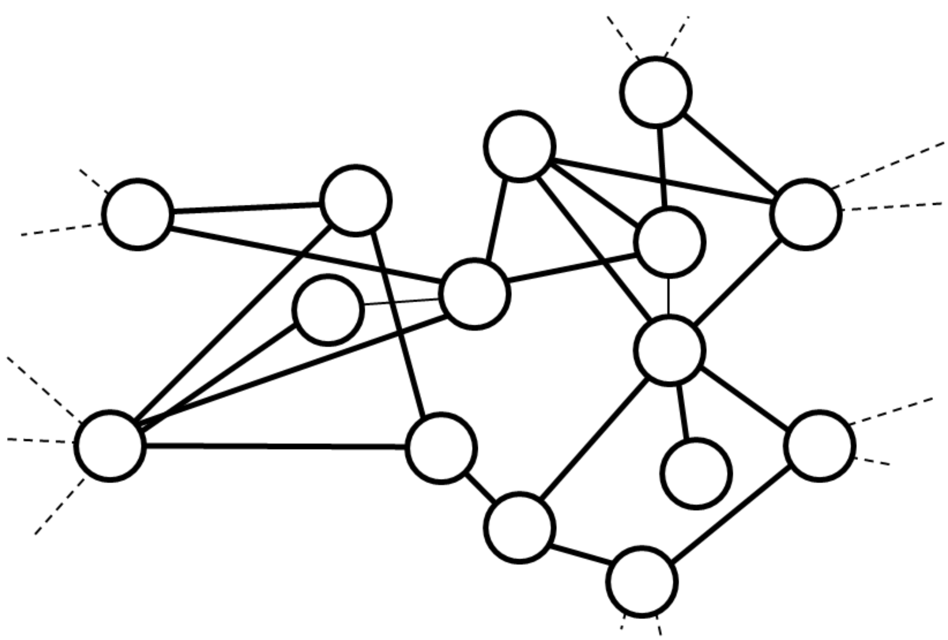

Figure 2: A network

ANT's assertion is that actors do not exist in virtue of themselves - but only are defined by their relationships to other actors in the network. According to Jensen (2004, p. 5), the network concept in ANT is very open. Thus are there no prior assumptions that the network has a special stability. Both a product and an organization can be considered as a network. There are no assumptions about size: both the microscopic to the universal can be included. Finally there are no assumptions that the network simply consists of one type of relationship (e.g. interpersonal). Rather, ANT analysis typically employs heterogeneous networks, i.e. a network that consists of many different types of relationships. Thereby ANT differentiates itself from Social Network Theory - which only operates with human actors and consequently focuses on interpersonal relations (Waserman & Faust 1994).

Actor

The second fundamental concept in ANT is the actor concept that is included in the network. Thereby it also has a focus on the elements of a system like the first strategy Fixson (2003) identifies. However unlike existing theories on modularity, ANT operates with a fundamental principle of symmetry, where human and non-human actors are treated equally (Latour 2005, Law & Callon 1992). What is in focus is whether they "make" a difference by being either the subject or object of activity.

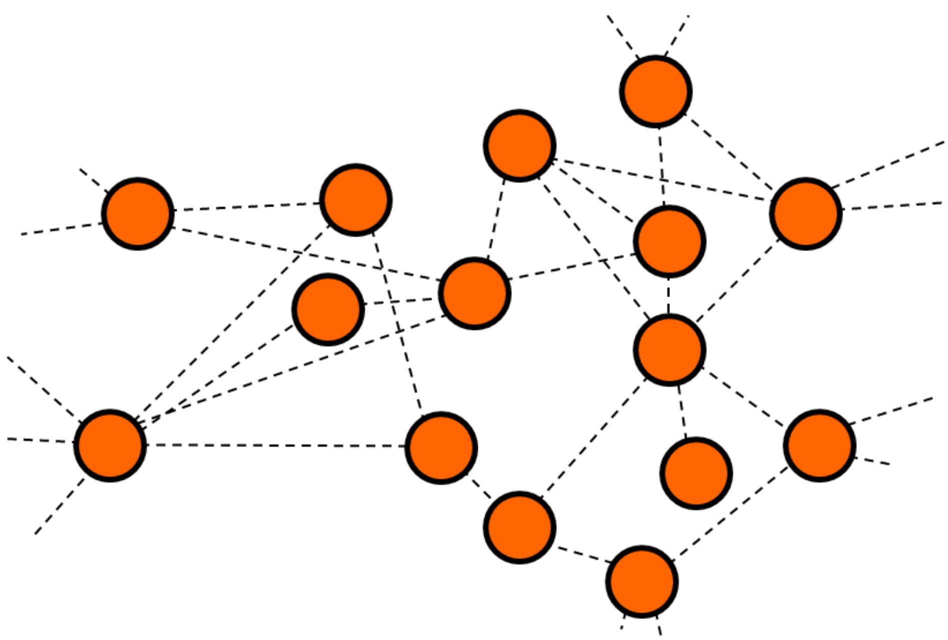

Figure 3: Actors in the network

An actor is attributed to the action going on in the network and can literally be anything as people, materials, tools, but also regulations and a weather phenomenon affecting the process can all be seen as actors. This open definition of the actor concept gives rise to confusion, since most other theories only use the actor concept in relation to human individuals. Thus this principle often generates an unproductive discussion whether non-human actors have agency or not. The way around such discussions is to address the issue empirically, rather than ontologically.

But if actors are not defined in virtue of themselves but by virtue of the act, how are actors then different from the network? According to ANT, there is no fundamental difference between actors and networks. Actors are networks that from a given perspective have developed stability and thus appear as a "black box". These defined units respond predictably to specific inputs while the internal processes are invisible to the observer.

It is exactly the concept of the black box which is connected to the concept of modularity. Modules represent groups of actors which have been stabilized over time. In this way modularity can be interpreted as black boxes of actors. This is particular the case of product and organizational modularity where they respectively can be interpreted as a stable collection of non-human actors and human actors as illustrated in the following figure.

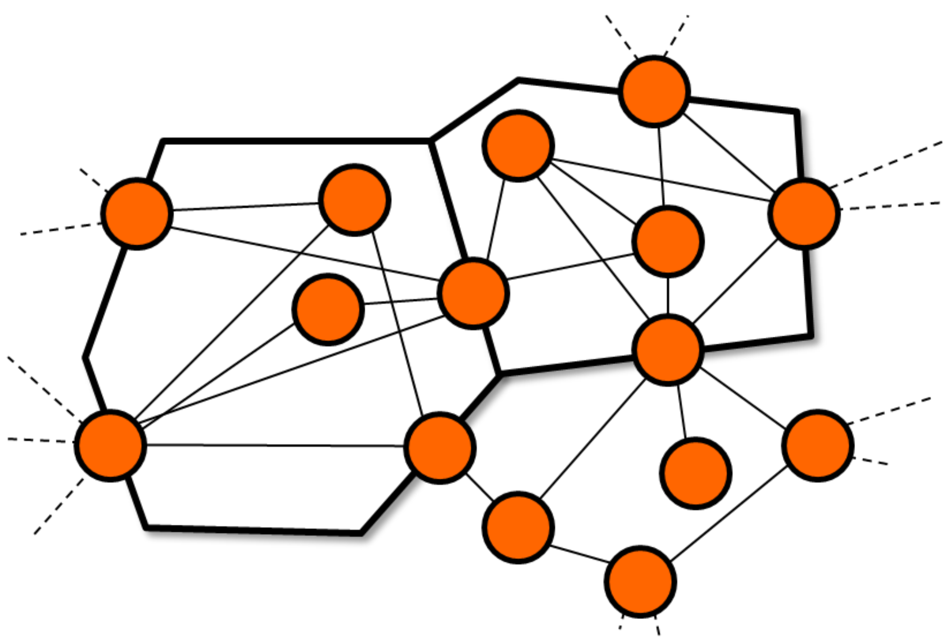

Figure 4: Modules in the actors network

ANT however doesn't only accept black boxes of either human or non-human actors. Thus Latour (1993) uses the term "hybrid" to illustrate that these can consist of both human and non-human elements.

The point of ANT's actor concept is that there is never any center where action originates from. Actions are achieved by arrangements in the network in such a way that one actor in the network acts on behalf of others. How long an actor can maintain their effect is an empirical question.

Translation

But how are processes then understood in the actor network? The early ANT tradition – which we here draw upon – analyses the dynamic element by the concept of translation, which covers how an actor obtains power by allying themselves with others (Callon 1986).

"Translation is the mechanism by which the social and natural worlds progressively take form. The result is a situation in which certain entities control others. Understanding what sociologists generally call power relationships means describing the way in which actors are defined, associated and simultaneously obliged to remain faithful to their alliances." (Callon 1986, p. 224).

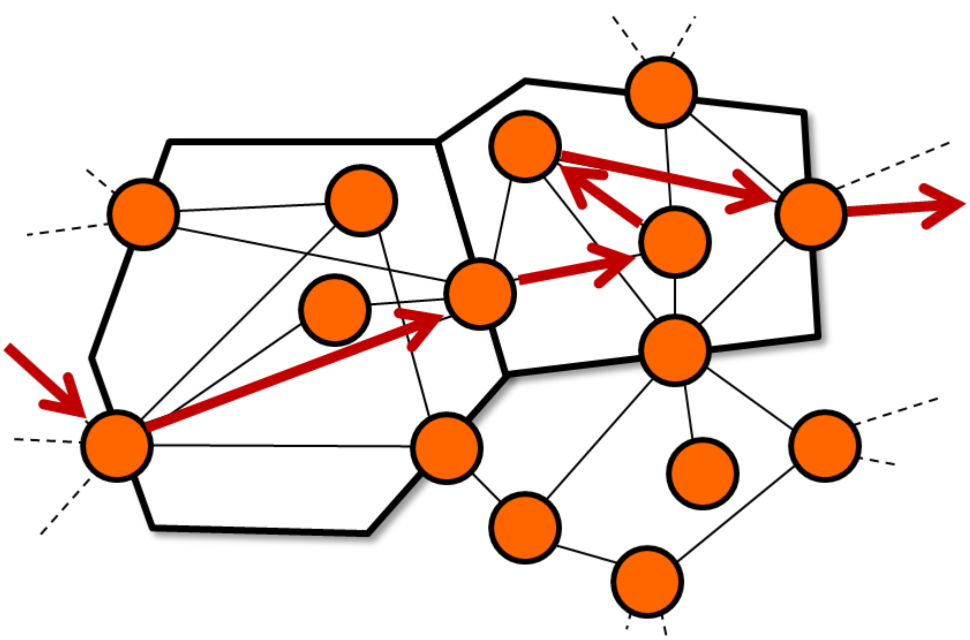

Figure 5: Processes in the actors in the network

Basically, translation processes links actors: a worker assembles as product in collaboration other workers based on a drawing from the design team. In this case, the actors are powerful because they are enrolled in a chain of prior actors. Thus represent the drawing the result of talks among designers. So when the drawing can come up with a fairly stable credibility, it is by virtue of a long chain of previous translations (processes).

A classic ANT strategy is to follow the translations in the actor network. The creativity in ANT therefore lies in the description of how the actor-network built up and stabilizes through translations in space and time.

Returning to the concept of modularity, the concept of translation enables us to explain and understand process-oriented modularity. While the translations cover all actions in an actor network, it is the premise for understanding process modularity. However given the stable characteristic modularity, not all translation can be interpreted as process modules. Process modularity might be interpreted as translation processes with a high degree of repetition among certain actors.

Analytical framework for studying modularity

The usual strategy in ANT is to follow how action is produced in the actor net through translations processes. Although this strategy is fruitful for an in-depth understanding of the modularity of a socio-technical system, it is also a challenging process.

A shortcut which might ease the analysis is by looking for elements of stability, standardization and repetition. Some guiding questions for analyzing different dimension of modularity of a system can be:

- The market dimension: To whom is it produced / delivered? (customer/user/market)
- The product dimension: What is produced / delivered? (product/service/experience)
- The organizational dimension: Who is producing / delivering it? (organization/practice)
- The process dimension: How is it produced / delivered? (process/practice)
- The institutional dimension: How is it influenced by institutional actors?

We will now use this framework in the analysis of the development the production system of construction in different time periods.

ANALYSIS

Pre-modern construction

As an example of pre-modern construction we will use the case of building works from Copenhagen, Denmark in the period 1850 to 1950.

The market dimension (customer/user/market)

As this period was characterized by a growing urbanization a shortcoming of housing and a market for flats arose. The new citizens of the city represented a rather homogenous group without any significant requirements for living rather than a job and a place to live.

The product dimension (product/service/experience)

Addressing the growing demand for housing 5 stories buildings was developed around the medieval center of the city. The buildings was produced by well know materials such as wood, tiles, and glass. An example of such building is illustrated in the following figure

Figure 6: Typical house from the period

The organizational dimension (organization/practice)

This period was characterized by professional craft guilds as carpenters, masons and joiners, developed around simple the well proven technologies / materials as wood, bricks, and glass. These crafts were sustained by apprenticeship learning processes ensuring a strong integration between design and production and the management of the crafts practices.

The process dimension (process/practice)

The main design was made by a master artesian, with some few drawings showing the plan view, sectional view and elevations. The design was made on the basis of exact knowledge about the building methods to be used, and this material could be given directly to masters in the relevant building trade who, with a limited amount of detailed planning, were able to carry out the work with methods that were learned in advance and used in all building processes.

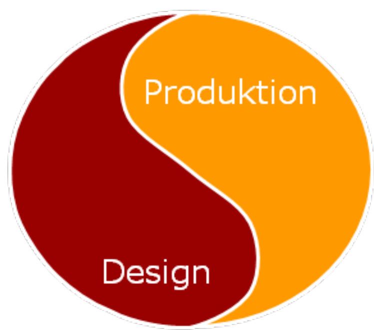

Figure 7: Pre-modern symbiotic relationship between design and production

The apprenticeship learning principles ensured the transfer of knowledge from master to apprentice, and from design to production. The characteristic of this knowledge was that it is tacit, embodied, and thereby is not directly communicable. The codification of knowledge was thus playing an inferior role. This is reflected of the often very limited use of drawings and description. Thus the vast majority of buildings was built with a basic overview and a illustration of the façade like illustrated in figure 6. The interpretation of the drawings was made possible by the tacit and embodied anchored in the form of rules of thumb (such as the rule for designing stairs 2 x (height of the step) + the length of the step = 2 feet).

This symbiotic relationship between design and production was made possible as the master artesian initially was educated within a craft guild. The premise of being allowed to design buildings was thus to master a practices of one of the central crafts. In this way it was made sure that the design effectively could be realized through the existing practices.

The institutional dimension

This development was regulated by several building laws/codes (1856, 1871, 1875 and 1889) by the city of Copenhagen. The code defined the lowest construction standard allowed and thereby buildings' quality level. The code contained detailed demands for the buildings' construction and materials, for example wall thicknesses and lumber dimensions. The traditional building custom of dividing crafts according to the materials used, such as wood and tile, functioned in combination with the code. Together, they set a clearly defined framework for this type of building for about 100 years (Engelmark 1983).

Example of the dynamics of the pre-modern modularity

Through social learning theories it is possible to develop an understanding how the modularity of this period was develop and reproduced like the following example of installing a window in a bearing wall by the mason and joiner.

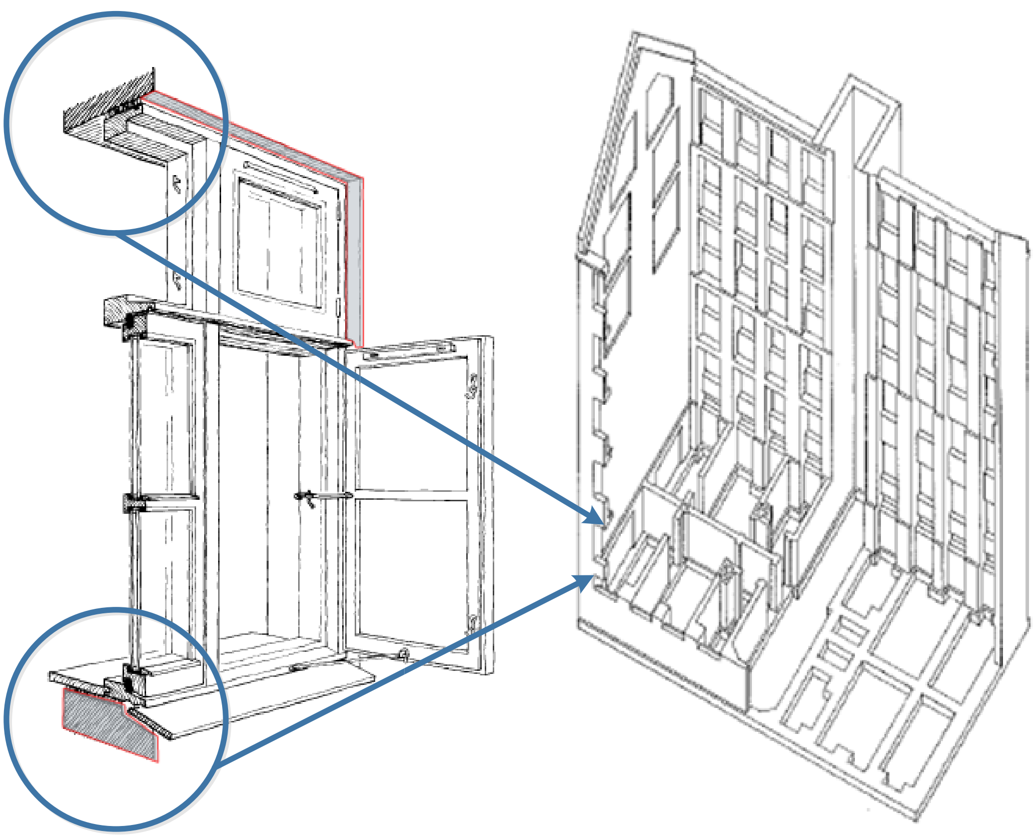

Figure 8: Interface between wall and window

The mason and the joiners had clear roles and rules for how and when their tasks was to be carried out, including standards for the wall's different thicknesses, how the variation in the wall's thickness should be handled, and the placement of the window frame. This enabled a standardized process for installing the window in the bearing wall, and a clearly defined exchange of information between masons and joiners. The interface between the bearing walls (module) the windows and doors (module) also defined the interface between the organizational practices of the masons and joiners (modules). As these interfaces were clearly defined it was possible to achieve an effective production while at the same time leaving room for creative decoration inside the module. This system was developed over many years and produced many similar buildings with different architectural appearances. In this way, the modularity went hand in hand with repetition and renewal and because of the high degree of repetition effective learning processes were developed.

The modern construction practice

After the WW2, the urbanization continued but the pre-modern construction practices couldn't keep up with the demand for homes. At the same time was concrete technology matured as a promising new construction material. These were some of the central premises for the development of modern construction practices.

The market dimension (customer/user/market)

The market was as aforesaid housing the growing urban population - a huge market. In 1945 the Ministry's Committee on Construction estimated that in the period until 1976 was to be built just over 1.5 million dwellings (Indenrigsministeriet 1946), an assessment subsequently proved to be on the low side. Thus a later report estimated that need had been just over 2 million (Bertelsen 1997). Given the population in Denmark post the WW2 was around 4 million people the profound size of this market is illustrated.

The product dimension (product/service/experience)

This market was satisfied by the construction of multistory buildings in the suburbs of the large cities – standardized homes for standardized citizens. This construction principle of buildings was enabled by introduction of materials such as concrete and steel which presented a fundamental different product modularity compared to the pre-modern construction practice.

It was however not only on the material side, there were changes. Inspired by scientific management subsystems of the buildings were standardized like concrete elements and installation components integrating water, central heating, ventilation and electricity in the buildings. Such components are illustrated in the following figures of concrete elements and an installation shaft from a bathroom.

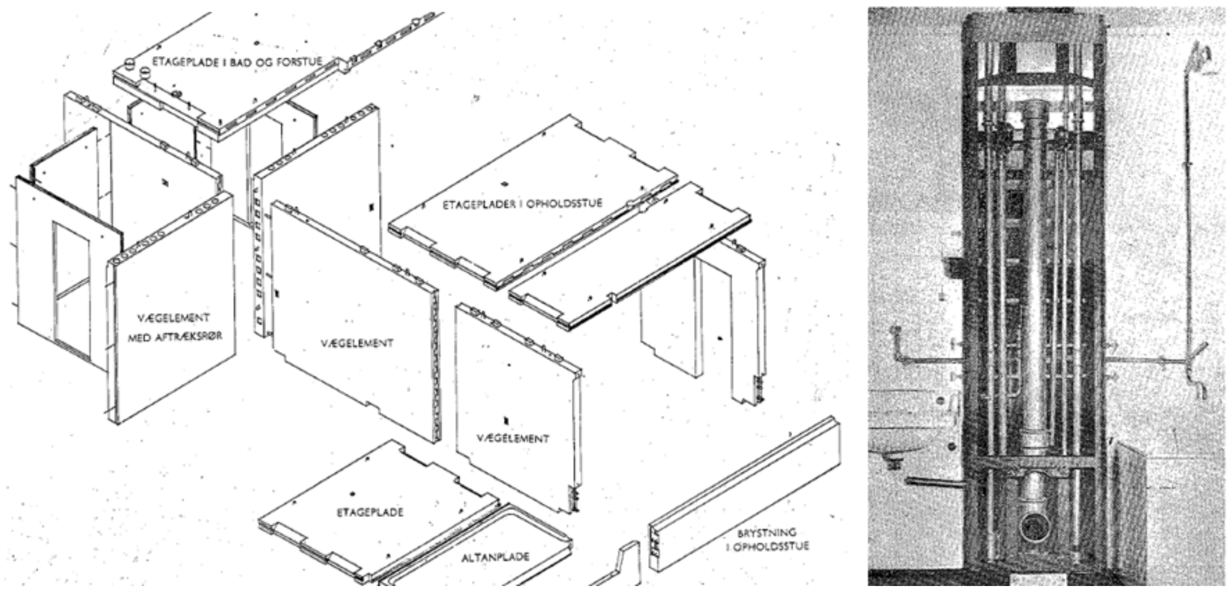

Figure 9: Standardized concrete elements and installations

This development came off - unlike the rules of thumb in the pre-modern construction – with a major focus on precision, tolerances, and measurement, as illustrated in the following figure of tolerances between modules.

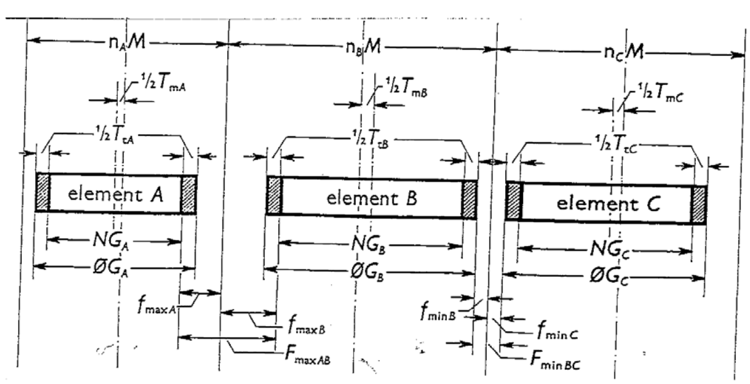

Figure 10: Tolerances between modules

The organizational dimension (organization/practice)

Also, the existing organization in the building industry underwent major changes during this period. As the growing population in the cities didn't have any jobs they represented an unskilled resource. They were employed as hourly paid workers by large contractors. These contractors were the primary actors in the production of the buildings covering design of the buildings, prefabrication of concrete elements, and assembly at the construction site ensuring efficient supply chains. Central to this develop was the introduction of the planning engineer as a profession, who had the total overview of the building process from the design process, prefabrication to assembly. Form being a craft oriented industry, construction became a science.

The process dimension (process/practice)

The development was inspired by scientific management know from Taylor (1912), thus were design and production now separated in clearly distinct phases symbolized by the phase model as "model" that provides overview and links the rational construction together, through clarity and transparency – illustrated by the following figure.

Figure 11: The modern separation between design and production

This also developed drawings and documentation from having played a peripheral role in the pre-modern construction practices into important technologies for communicating design decisions which all had to be taken in the design phase by the architects and planning engineers.

Central to the industrialization of the construction process was that they considered buildings as something standardized targeting generic human needs (standardized citizens). This is symbolized by the architectural credo "form follows function" initially formulated in 1852 by the American sculptor Horatio Greenough (McCarter 2010). This helped to develop the myth of the standardized building, which made the construction process transparent from a single point (the planning engineer), enabling long term planning of the construction from start to finish.

Finally the industrialization made the building process a subject to mechanization - exemplified by the use of cranes. The cranes were needed to mount the heavy concrete panels, with the implication that the design of the dwellings were optimized with respect to the technological limitations, the cranes had. The result was that housing was designed so that they followed the tracks of the crane (illustrated in the figure below).

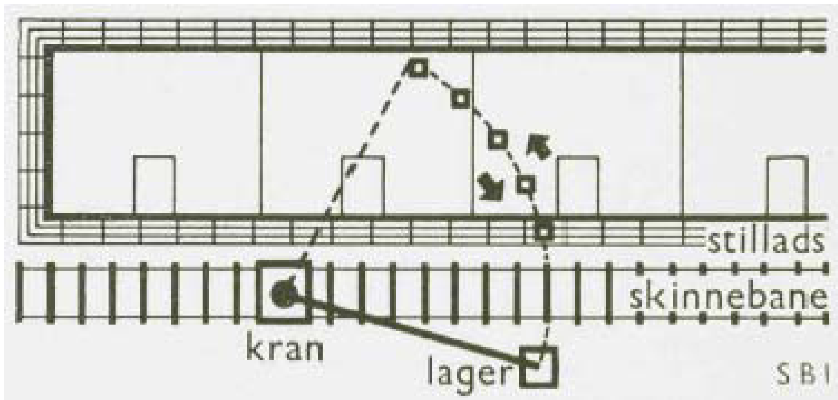

Figure 12: buildings defined by the technological limitations of cranes

The institutional dimension

The driver of the development of the modern construction practices was a strong state intervention in the industry through regulation. It started in 1947 with the creation of the first ministry of Construction and Housing. Through a long series of laws and regulations the ministry subsequently developed and enforced a shared agenda in industry. This included the development of sectorial research institutions in order to provide the scientific basis for the agenda.

Example of the dynamics of the modern modularity

One of the classic examples of modern construction practices is the building the Empire State Building. In just 18 months, this building was realized from the initial design to the inauguration. The production was done according to the principles of scientific management in general and the assembly line in particular with the only significant difference that here it was the workers who moved in relation to the building (product) and not the product that moved relative to the workers as it was otherwise known from the automotive industry. This planning method which goes under the name Line of Balance is shown in relation to the planning of the Empire State Building (figure13). Pay special attention to how the planning in addition to handling the time dimension (horizontal) also includes the location (vertically).

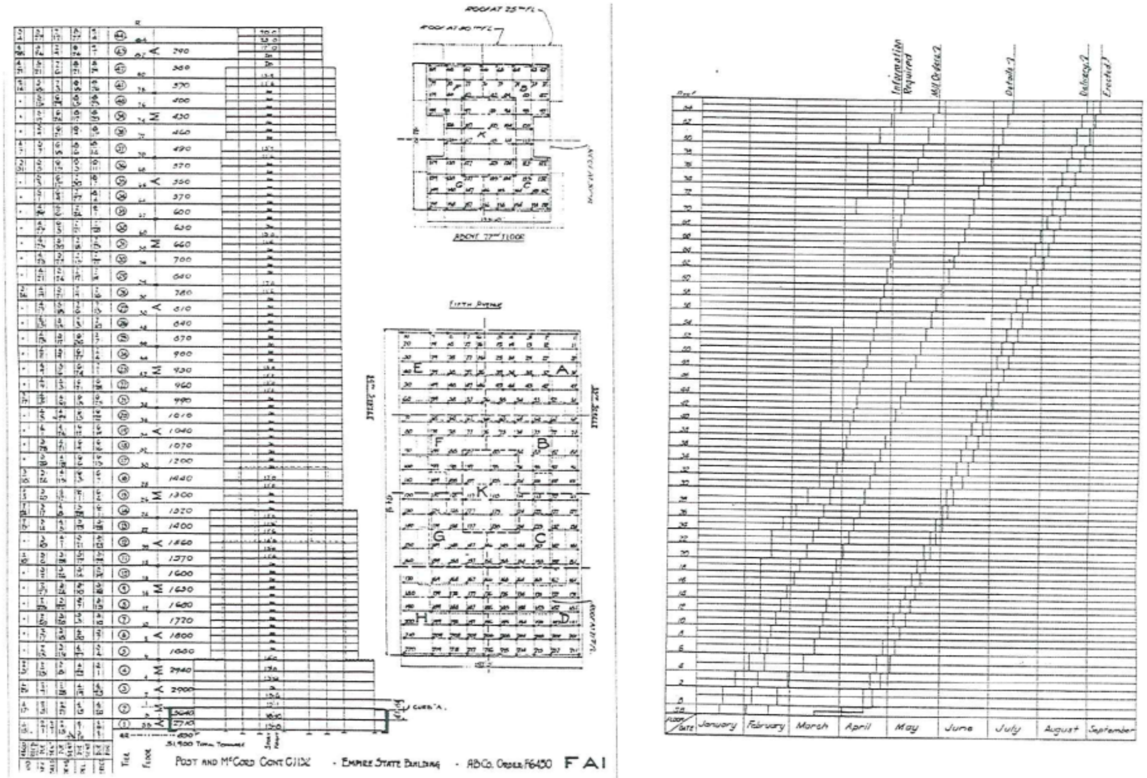

Figure 13: Modern planning practice of the Empire State Building

This combined with a strong focus on planning and controlling work in relation to provision of materials and workers in the right place and time, allowed the production of one floor a day and that the whole structure was completed in just 4.5 months - an achievement which is difficult to repeat with the construction practices of today.

The post-modern construction

After the shortcoming for housing had been addressed, there was no longer a central societal problem to be solved. At the same time, the 68' revolution of society gradually broke down the modern building practices and overtime post-modern construction practices evolved.

The market dimension (customer/user/market)

From being driven by production of standardized multistoried buildings the production of housing in the beginning of the post-modern was driven by construction of buildings with large variation targeting more individualized customers – unique project for unique customers.

Subsequently, the market has gotten increasingly heterogeneous, characterized by large cyclical fluctuations.

The product dimension (product/service/experience)

On the technological front, the post-modern building is characterized by an explosion of new building materials and technical and complex solutions that support the realization of customer's unique needs. The consequence is an ever-increasing complexity in construction. An exemplary case on this issue is the post-modern installation shaft. Back in the modern period installation shafts were mass produced just like the prefabricated concrete elements for the structural part of the building. But from the 80' and onwards the shafts have got increasingly complex, and contains a lot of new features. Consequently an average installation shaft consists of approx 300 operations among 9-10 technical crafts, done on 0,6 x 0,8 m with one-sided access and impossibly working conditions (Thuesen and Hvam forthcoming). An example of such a shaft is show in the following picture – notice the deferens to figure 9.

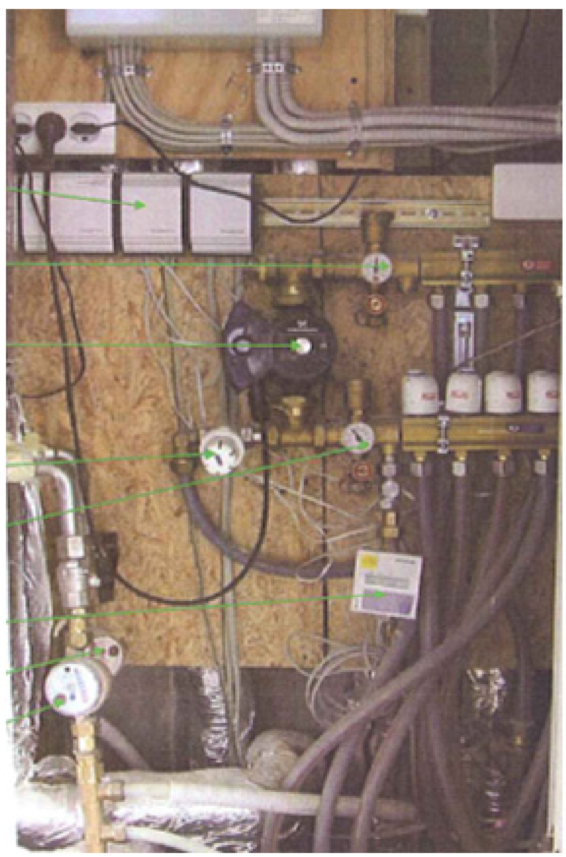

Figure 14: post-modern installation shaft

Thus the installation shafts are illustrating the lack of ability to control the complexity of the construction process. Although everyone has a share in the design and production of the shaft nobody takes full responsibility for the realization of the shaft.

The organizational dimension (organization/practice)

Also the organization of the industry has undergone changes in the post-modern construction through including new roles such as client advisors, new crafts, and material producers. In contrast to the modern construction, where it was the contractors who had customer contact with the professional client (the state), contractors today rarely have the first customer contact. This role is handled primarily by the architect or client advisors who help the customer identify his or her needs.

This development put the big contractors under pressure, which meant a sale of their material-producing parts and acquisitions by international contracting companies such as NCC and Skanska. The consequence has been that the integrated value chain from the modern construction practices started to disintegrate. Thus the construction industry today is characterized by having a fragmented value chain.

The process dimension (process/practice)

Design wise the architects freed from the modernist rationality illustrated in the post-modern architectural credo "form follows fiction". The consequence has been a drift towards constantly exploring new architectural possibilities at the cost of closer integration with production. The more radical architecture combined with the introduction of new professions and an explosion of new technologies has made managing complexity the key challenge for the post-modern construction practices. Thus the design and production today has drifted apart as illustrated in the following figure.

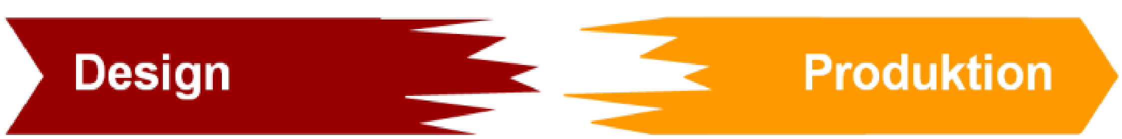

Figure 15: post-modern fragmentation of design and production

One of the strategies for dealing with the increasing complexity of the construction practices has been the adoption of information technology such as CAD and document handling systems.

But also social technologies around new forms of cooperation have been used to manage the complexity through dialogue. This is illustrated in the revised schedule below that is less detailed compared to the the ones from the modern period omitting the locational perspective. In turn, it is signed by all project managers from the participating companies as a symbol on a shared commitment to the revised schedule.

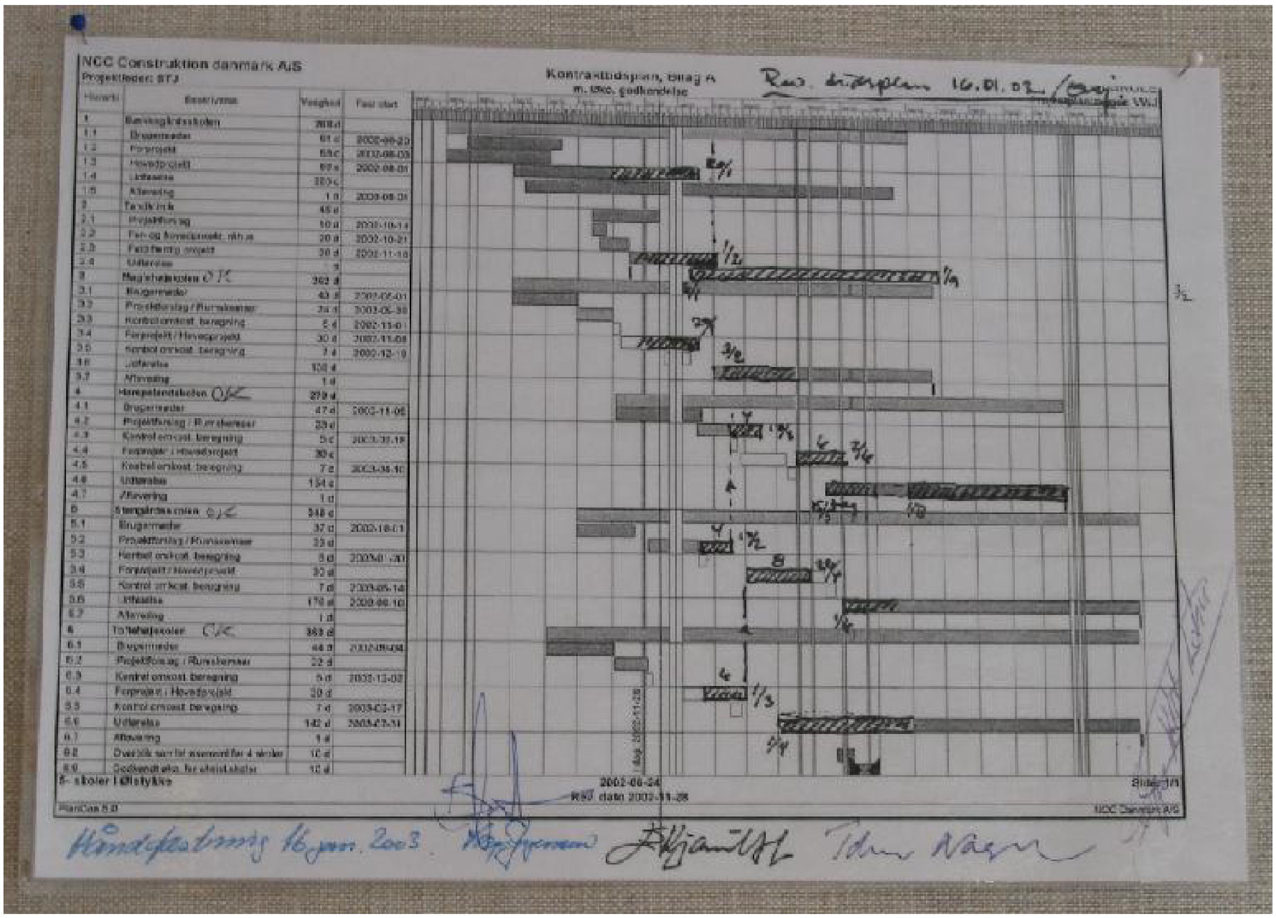

Figure 16: post-modern time schedule

These elements have been organized as tools and strategies for navigating in a chaotic and imperfect project and have been inscribed in a Project Management discourse differing from the inspiration in the scientific management in the modern period. The “project” became the vehicle for realizing buildings – and project management became the management principle. This is still the predominant way of organizing and managing the building process today.

The institutional dimension

After meeting the societal need to address a large unemployment and the provision of housing for the growing city's population, the construction industry gradually lost its urgent socital importance. It also meant that the effort to regulate the industry could not only focus on housing, but had to focus on the entire industry. This new focus was in particular illustrated by resource area analyzes up through the 90s. Through these analyzes, the industry was articulated as an industry which lacked behind other industries e.g. with respect to productivity.

Example of the dynamics of the post-modern modularity

As an illustration of the dynamic of the post-modern modularity we will now turn to a specific instance in a project (the picture) where two carpenters install a window under the supervision of a construction manager (red helmet).

Figure 17: Example of post-modern construction practices

The building project which in this case is a construction of a school is realized by developing and organizing various product, process and organizational modules. The interface between the different product modules, like the windows and concrete floor, is mirrored in the modularity of the professions. Thus the carpenters take care of the woodwork including the windows, while the concrete workers are responsible for the foundation and the placement of the concrete panels. This organization of the modularity is partly institutionalized by the professions, educational system and interest organizations partly locally designed and negotiated within the project. The carpenters practice is designed in the project by drawings and descriptions made by the architects and engineers and plans by the construction management. These “rules” for e.g. the placement of the glue laminated timber and the windows, sets the context for local negotiations among the carpenters of actual ways of carrying out the installation of the windows taking past experiences and personal motivation into account. Within the boundaries set by the institutional forces, the designers and managers of the project the carpenters might improvise and develop their own practice. As long as they improvise within the boundaries of their module/profession, the modularity of the project is reproduced. In this way, modularity goes hand in hand with repetition and renewal.

The design enables a somewhat repetitive process for installing the windows in the building. However due to the unique design of the school the repetition only occurs within the project making it more difficult to develop effective learning processes across projects... especially when compared to the pre-modern and modern construction practices. This lack of continuity in the learning processes is one of the most important explanations of the construction industry low productivity today.

Summary

The following two tables summarizes the socio-technical modularity of the different construction practices and identify the characteristics of the modularity.

Modularity	*Pre-modern*	*Modern*	*Post-modern*
Market	Class, Urbanization, housing, stable demand	Class, Urbanization, Housing, stable demand	Individual, heterogeneous fluctuating demand
Product	Crafted buildings **Types:** Flats **Material:** Wood, bricks, glass	Standardized buildings **Types:** Flats **Material:** Steel, concrete, insulation, glass water, electricity, heating,	Unique buildings **Types:** All types **Material:** Wood, bricks, glass, concrete, insulation, alu facades, steel, water, electricity, heating, ventilation, IT, automation, fire
Process	Design and production integration Simple drawings	Design and production separation Detailed drawings, detailed plans, industrialization and mechanization Scientific management	Design and production fragmentation Drawings, plans, IT, collaboration, lean, partnering, mechanization, industrialization Project management
Organization	Crafts: Masons, carpenters, joiners, Designers: master builder Managers: master builder	Unskilled workers Crafts: carpenters Designer: Architects, engineers, contractors Managers engineers, Contractors	Unskilled workers Crafts: masons carpenters, plumbers, electricians, Designer: Architects, engineers, contractors Managers engineers, Contractors
Institutional	Limited regulation, Building code	Strong central regulation, competitive bidding, tendering systems, shared standards and general conditions for work and supply	Week central regulation, competitive bidding, tendering systems, shared standards and general conditions for work and supply, partnering, strong interest organizations

Table 1: Summary of the modularity of the different construction practices

Modularity	*Pre-modern*	*Modern*	*Post-modern*
Value chain	Integrated	Integrated	Fragmented
Boundaries	Culturally well defined	Scientifically well defined	Blurred and locally negotiated
Degree of repetition	High repetitiveness	High repetitiveness	Low repetitiveness
Complexity	Low	Low	High
Productivity	Medium	High	Low

Table 2: Characteristic of the modularity of the different construction practice

The analysis has shown how the modularity constantly is in the making. New modules arise, existing modules are altered and some even disappear like joiners which today are a sub group of carpenters. The radical changes in the modularity of the production system has come about through, market changes, changes in society and through policy making.

Looking into the differences between the modularity of different periods it is striking to see how the complexity have exploded compared to the pre-modern and modern construction practices. Thus today's post-modern construction practices are facing a low degree of degree of repetition, high complexity resulting in low productivity. Using the metaphor of a puzzle as a symbol on the modularity you could argue that more and more pieces are added to the puzzle, increasing the complexity. But when the pieces in the pre-modern and modern construction practices fitted neatly together due to the culturally and scientific defined interfaces, the many pieces represented in the post-modern puzzle is somewhat incompatible requiring a high degree of rework in order to make them fit.

DISCUSSION

In the following, we will discuss the consequences of the socio-technical interpretation of the concept modularity.

Modularity is a matter of perspective

As Campagnolo & Camuffo (2009) note, modularity is a characteristic of a system but also a matter of perspective. What from one perspective appears as a stable module might from another appear as a subsystem of modules, elements and actions. These differences might stem from different professional backgrounds and different approaches for understanding modularity. From a future user of the building, the construction organization might appear as a stable but rather chaotic entity but for a craftsman or project manager, it is a dynamic but yet ordered power struggle between different crafts, apprentice, project managers and materials.

Most strands of theories on modularity seem to have a rigid separation between social and material actors and presuppose certain types of analytical categories like organizational, supply-chain, process and product modularity. By focusing on actors, networks and translations, ANT rejects preexisting analytical categories. What characterizes the modularity of a socio-technical practice is in that sense an empirical rather than a theoretical question. Thereby new types of modularity might evolve from an empirical analysis like institutional modularity, tool modularity and modularity of practices. Revisiting the post-modern example, the straight-forward interpretation of the modularity would be that the carpenters and construction manager represent the organizational modules. A more honest interpretation would see the professions as institutionalized practices - a socio-material configuration of persons and artifacts. For instance, the carpenter's practice of installing the windows is based on rules of thumb, drawings, information about material, and so on. But it is also enabled by a deep understanding of the physical possibilities and limitations in relation to the windows rooted in past experiences from other building projects. Since such an understanding is developed though generations, the modularity is also historical. Finally the practice is influenced by regulations like safety issues, building codes, and tendering systems adding an institutional dimension to the modularity.

It is this sensitivity towards the empirical domain that makes it possible to investigate the modularity of different types of socio-technical systems, without subscribing any existing analytical categories any importance like product, process and organizational modularity.

Modularity in the making

Basically the concept of modularity is a concept of stability but the dynamic ontology which Actor Network Theory is based upon enables us to understand the dynamic processes of the modularity of a socio-technical system.

ANT describes a world of networks, which constantly stabilize and destabilize. The translations in the actor net generate a socio-technical order but this order is sometimes fragile. Networking therefore implies a constant struggle to enroll and discipline the actors. Every time an actor is at the end of a translation process and thereby increases their strength, there is a kind of deflection, exploitation or abuse that makes the winning position fragile.

The consequence is that the modularity of a system is always in the making. The modularity is just as much the result as well as premise for action. It is both the means and the end. This characteristic enables us to understand social learning processes of modularity, exemplified in practices based theory (e.g. Nicolini et al 2003).

Understanding and managing the modularity of a socio-technical system

The interesting question is not whether a system is modular, but what characterizes the modularity of the system. Given this insight in modularity as exemplified in the analysis, it is tempting to ask the question: “How can the socio-technical modularity be designed and managed?”

Since ANT is not a normative strategy, it doesn’t directly address practical managerial issues. As has been shown, ANT is able to understand modularity but it is not concerned whether it is good or bad.

Despite the lack of normativity in ANT, it might inform better managerial actions by developing a more robust understanding the modularity of a production system, especially combined with existing modularization tools.

The modularity of a socio-technical system as we saw in the analysis might be seen as a puzzle where the pieces fit more or less together. If the pieces fit well together, the system will be characterized by efficiency and high reliability, but if the pieces do not match resource are needed to negotiate and align the interfaces resulting in inefficiency and uncertainty. Consequently the traditional managerial practices strive for developing systems with a well-defined modularity. On the other hand it is important to notice that a poor modularity introduces uncertainties which offer potential elements for creativity and innovation.

Directions for further studies

As most existing modularization techniques have been developed from a mass production context characterized by stability, they might have a limited field of application in relation to other socio-technical system like the construction industry, which is characterized by strong institutional forces, volatile markets and hyper complex production practices. In line with the saying "For a hammer everything is a nail", there is a danger that we might use developed tools inappropriately. Thus it is important to have a reflexive approach, being sensitive to the empirical field in the development/modification of tools and practices to study, design and manage modularity. This opens up a research agenda regarding:

- Clarification of the concept of Modularity (theoretical and practical)
- Conducting empirical analysis of the modularity of different socio-technical systems
- Development of tools and practices for studying, designing and managing modularity.

CONCLUSION

This article has offered a new interpretation of the concept of modularity enabling a more honest understanding of socio-technical production systems. Based on the dynamic, socio-material perspective within Actor Network Theory, the approach enables us to:

- identify different types of modularity based on a empirical sensitivity covering modularity is relation to organization, products, process, tools, institutional, and practices
- link the different types of modularities

- grasp the dynamic nature of socio-technical systems and thereby understand modularity as a process rather than something stable
- understand the learning processes of a modular system making it possible to understand how the modularity is reproduced

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